How digitalisation can enable Industrial Symbiosis practices: a case study

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Abstract
Industrial Symbiosis (IS) encourages a collaborative approach aiming at recovering, reprocessing and reusing non-labour resources and it is a promising solution for mitigating the rising cost of non-labour resource. Introducing IS is a knowledge intensive process and researchers have developed various information and communication (ICT) tools to support the process. However, the use of these tools in the actual industrial practice has not been adequately investigated yet. This study investigates the role that ICT tools play in facilitating the process of creating IS through a case study of International Synergies – the company which facilitated the world's first national-level IS programme (i.e. NISP UK). Results suggest that the role of digitalisation can increase practitioners' productivity mainly through data analytics.

Keywords: industrial symbiosis, sustainability, recycling

Introduction
Industrial Symbiosis (IS) encourages a collaborative approach aiming at recovering, reprocessing and reusing non-labour resources (WRAP, 2014) and it is a promising solution for mitigating the rising cost of non-labour resource (Ellen MacArthur Foundation, 2013; Gregson et al., 2015). Recent studies (see e.g. Lavery et al. 2013)

suggest that an improved productivity of non-labour resources could generate 12% additional profits, 12% increase in manufacturing employment as well as 4.5% reduction of carbon emissions for UK manufacturing industry. Establishing IS transactions requires a process of facilitation and coordination (Chertow and Ehrenfeld, 2012) and various barriers (e.g. informational, technical, economic) have been recognised (Golev, Corder and Giurco, 2015).

Addressing these barriers, researchers and practitioners developed various information and communication technology (ICT) tools to support the process. These tools manage the information flow enabling IS linkages between companies from disparate industrial sectors, but most have since fallen from use (Grant et al., 2010). Currently, digitalisation is increasing the amount and sophistication of tools; recent examples include cloud-based platforms featuring dynamic databases and recommendation algorithms that promote collaboration by matching traditional and non-traditional industrial waste streams with novel product and revenue opportunities (SHAREBOX, 2017; MAESTRI, 2017; LifeM3P, 2017; The Materials Marketplace, 2016; Song et al., 2015; Raabe et al., 2017; Song et al., 2017; Low et al., 2018). These tools have been typically developed and tested by researchers under controlled conditions, while the possibility of using them in the actual industrial practice has yet been adequately investigated.

In light of the mentioned gap, the purpose of this study is to analyse the process of establishing IS in practice and to investigate the role of digitalisation, enabled by advances in ICT tools, in facilitating this process.

Research Methodology

In this study, a single in depth case study approach (Yin, 2013) has been selected to study the actual practice of facilitating the creation of IS. The case study approach has been selected as it enables the gleaning of rich information sources to build a more complete picture of how inter-firm IS networks are developed over time (Halinen and Törnroos, 2005; Paquin and Howard-Grenville, 2013). Based on triangulation of multiple data sources, the validity of the findings is ensured (Yin, 2013). Table 1 provides a summary of the data sources utilised in this study.

Table 1: Data sources used in this study

Data sources	Purpose
Interviews	
• Interviews with Chief Executive of International Synergies • Follow-up interviews with IS practitioners	• Investigate the process of creating IS-based relations among firms at the operational level. • Investigate the tools employed to assist in the process of network creation in practice.
Secondary data sources	
• Academic literature on NISP network orchestration • Publicly available information on International Synergies and NISP • Academic literature and publicly available information on tools supporting Industrial Symbiosis	• Gather initial information regarding the process of establishing IS as well as the available tools designed to support the process. • Triangulate the findings with interview data.

Based on the data sources identified, the case study is carried out in two phases. In the first phase, a conceptual framework on the IS creation process is developed based on the combined analysis of the studies on the process of IS network orchestration, as well as the domain of developing decision support tools for IS. In the second phase, fieldwork will be performed in the form of industry interviews to refine and revise the conceptual framework established in the first phase.

Case selection and literature review

The case study company selected for this study is International Synergies Limited (ISL). The reasons for selecting ISL as the case study are twofold – empirical evidence of performance and exemplary instance in practice. Firstly, empirical evidence from the literature suggests that the *facilitated* model of IS creation is capable of methodically organising IS on a large scale. Secondly, ISL has successfully established the National Industrial Symbiosis Programme (NISP) in the UK – the world's largest coordinating entity of by-product reuse among business sectors (Lombardi and Laybourn, 2012; Chertow, 2007) – through the *facilitated* model. These two factors will be further elaborated in the following.

The phenomenon of IS manifests in practice through three key models – *self-organised*, *planned* and *facilitated* – each model being characterised by its distinctive creation routes respectively (Patala et al., 2014).

While the *self-organised* model is the earliest form of recorded industrial recycling network (Desrochers, 2004) and is also the basis for which the renowned Kalunborg eco-park was formed (Branson, 2016), it heavily relies on serendipity (i.e. randomness and chance). This is evidenced by Chertow (2007), who described that IS uncovering event occurs "at some unspecified time". Therefore, the *self-organised* model lacks control over time and space.

In contrast, the *planned* model is empirically less successful in implementing IS in a self-sustaining way. As recently mentioned by Diemer (2017) and corroborated by other researchers (e.g. Ehrenfeld and Gertler, 1997; Andrews, 1999; Gibbs, 2003; Gibbs and Deutz, 2005, 2007), empirical research on the IS creation process suggests that the *planned* model – typically in the physical form of eco-parks (EIPs) – is associated with low odds of materialising IS in a sustainable manner. Gibbs and Deutz (2005, 2007) stated that EIP development is difficult through policy intervention. Challenges in tenant recruitment was a frequently cited issue, linked to conflicting regulations which limits opportunities for waste reutilisation (Gibbs and Deutz, 2005) and restrictive entry requirements for EIPs (Gibbs and Deutz, 2007). Technically, the diversity of flows may also make planning for IS difficult to organise (Gibbs, 2003).

As suggested by Chertow and Ehrenfeld (2012), *facilitation* and coordination is required even for the *self-organised* models to "sustain the norms" as well as to improve collaborative opportunities as they evolve. Compared to the *self-organised* model, the *facilitated* model allows for an accelerated timeline in the creation of IS. Additionally, the *facilitated* model is not inherently random by time or by place. For instance, the *facilitated* model has resulted in the creation of the world's largest IS programme documented in the literature – the National Industrial Symbiosis Programme (NISP) (Laybourn and Morrissey, 2009; Lombardi and Laybourn, 2012; Lombardi and Peter,

2006). Instead of decades taken by the *self-organised* model, the facilitated model in the case of NISP took approximately five years, beginning from its initial pilot phase in 2003 to delivering tangible results equating to an estimate of £1.5 billion to £2.4 billion Total Economic Value Added to the UK economy, as well as seven million tonnes of landfill diversion and six million tonnes of CO_2 reduction (Laybourn and Morrissey, 2009). Presently, International Synergies Limited (ISL), the organisation behind the success of NISP is actively carrying out its knowledge and practice transfer activities across the globe, including Belgium, Canada, China, amongst others (International Synergies, 2017). This showcases that IS can be flexibly deployed in a diverse range of geographic and time contexts under the *facilitated* route and not be adversely constrained by randomness associated to the *self-organised* route or hindered by the historically low success rate of the *planned* route.

Table 2 summarises the attributes of the *self-organised*, *planned* and *facilitated* routes of IS creation.

Table 2: Summary of IS creation routes

Attribute	**Self-organised**	**Planned**	**Facilitated**
Occurrence of success cases	High	Low	High
Approximate timeline of creation	~decades	~years	~years
Control over time	No control; inherently random	Yes; conscious planning	Yes; conscious organisation
Control over place	No control; inherently random	Yes; conscious planning	Yes; conscious organisation
Examples	Kalundborg eco-park; Kwinana; Gladstone	Devens Planned community; Londonderry EIP; Brownsville EIP	National Industrial Symbiosis Programme (NISP); Tianjin Economic-Technology Development Area (TEDA)

Phase 1 findings

Theoretical framework

According to various authors (Massard and Erkman, 2007; Lowe, 1997), IS creation first starts with preliminary assessment. This step comprises an understanding of the regional context (e.g. nature of companies) and gathering data such as material and energy information of the area of interest. Tools that support this step include the habitat suitability index for identifying areas with better prospects of developing IS (Jensen et al., 2012)and the maturity assessment for assessing and tracking an area's maturity towards IS(Golev, Corder and Giurco, 2015).

Following that, business engagement is carried to recruit participants (Massard and Erkman, 2007; Paquin and Howard-Grenville, 2012). The key purpose of business engagement is to garner interest in businesses and subsequently form a network that is fundamental for subsequent steps. Typically, business networking events (Paquin and

Howard-Grenville, 2012) and site visits are carried out to engage businesses (Massard and Erkman, 2007).

The key activity in creating IS is opportunity identification, whereby opportunities for IS connections are identified (Paquin and Howard-Grenville, 2012; Massard and Erkman, 2007; Lowe, 1997; Grant et al., 2010). Essentially, compatible input-output flows are discovered at this step which serves as the fundamental permitting condition for further pursuit of the IS opportunities. Various approaches and tools exist supporting this step, including databases to find suitable matching (Brown, Gross and Wiggs, 1997), online waste exchanges (Dhanorkar, Donohue and Linderman, 2015) and expert knowledge (Paquin and Howard-Grenville, 2012).

Business feasibility is an implicit process, often as a follow-up activity after opportunities identification. The activities include defining volume requirements, processing technologies required (Lowe, 1997) and accounting for other economic and environmental factors (Massard and Erkman, 2007). In terms of tools, economic considerations are often embedded in optimisation tools to find the best combinations of IS flows (Rubio-Castro et al., 2010; Taskhiri, Tan and Chiu, 2011).

Implementation and monitoring is whereby the IS opportunities come to fruition. Participating companies carry out the necessary business activities to realise the IS opportunities identified. The tools supporting this step focus on the monitoring aspects after implementation (Dai, 2010; Chertow and Lombardi, 2005), which provide indicators to track tangible achievements of the symbiotic exchange.

Finally, documentation is carried out to capture success cases to be used for attracting new participants (Grant et al., 2010). Tools that support this step include the CRISP system, which acts as a project management tool as well as documenting the process (*Ibid.*), and ontology for capturing common attributes of IS cases (Nooij, 2014)

Based on the literature review conducted in Phase 1, a theoretical framework is constructed, shown in Figure 1.

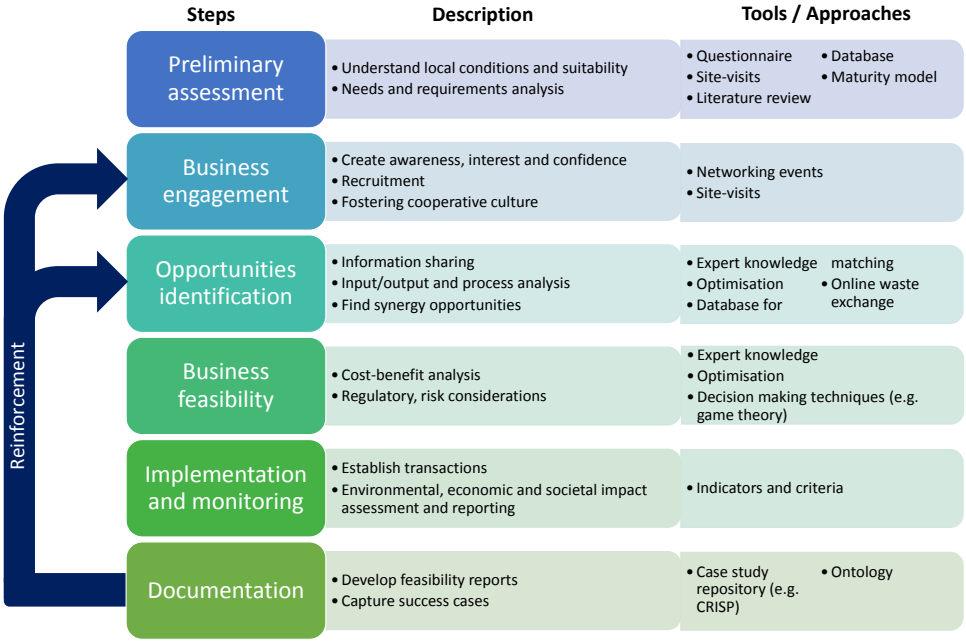

Figure 1: Theoretical framework for IS creation process and supporting tools / approaches

Phase 2 Findings

The interviews are still ongoing, but preliminary results have gathered the elements required for IS creation and the support tools used based on the case study company's context.

Elements for IS creation and support tools

Table 3 summarises the elements utilised for creating IS in the context of ISL.

Table 3: Elements for IS creation

Elements	Purpose	Tools and approaches
Building the network	• Recruit new business members • Access a diverse range of resources, expertise, sectors, business sizes and locations	• Industry databases used to fill in gaps identified in membership profile
Quick Wins Workshop	• Facilitate exchange of information between businesses	• Proprietary templates • Workshop methodology • Interactive sessions • IS Practitioners' knowledge and experience • Post-workshop report
Opportunity mapping	• Record resources • Facilitate potential matches • Identify required innovation	• IS Practitioners' knowledge and experience (*see Facilitated synergy – Role of practitioners*) • SYNERGie® (*see SYNERGie® Management System*)
SYNERGie® Management System	• On-line tool • Information on resource details • Tacit information and case studies	• Information search and retrieval • Database of IS cases • Information exchange and support tool for IS practitioners
Facilitated synergy – Role of practitioners	• Progress opportunities • Facilitate negotiations • Removal of barriers	• Industrial experience and knowledge • Professional judgement

Firstly, building the network must be accomplished through engaging the industry. This element serves as a foundational step in the process of creating an IS network. The main activity in this element involves the recruitment of new business members, which provides ISL access to businesses from a diverse range of sectors, sizes and locations. This activity aims to form a diverse mix of industry among members, which is also found to enhance opportunities for forming IS transactions (Jensen et al., 2012). In terms of execution, ISL initiates the activity through leveraging various existing industry organisations' meetings and conferences to disseminate information and garner interest in IS. To aid this activity, larger corporates and SMEs are also leveraged to bring in their

supply chain partners to drive further member growth. Additionally, "business champions", which comprise larger influential industry members, are engaged to disseminate real-life success cases and best practice sharing on a peer-to-peer basis to cascade best practices as well as to garner further interest from other companies. Through the range of recruitment activities, ISL is able to exercise "working with the willing" strategy, whereby interested parties will be invited for subsequent follow-up activities. This serves as an initial filtering process in member recruitment for ISL. Supplementing the recruitment activities, industry databases are utilised as a means to identify other relevant members to fill in the gaps in expertise and resources of the existing members.

The Quick Wins Workshop (QWW) is a follow-up activity that is organised after the initial membership recruitment activities. Industry members are gathered in these QWW sessions which enable the exchange of information between businesses though sessions facilitated by IS practitioners. Examples of information exchanged include the "wants and haves" for each business entity as well as the problems that they are facing. These QWWs – which aim to capture "low lying fruits" (Paquin and Howard-Grenville, 2013) – are intended to rapidly achieve success cases which are critical for the propagation and continuation of IS activities.

Closely related to QWW is the activity of opportunities mapping. IS practitioners will identify potential synergies among the participating companies based on information gathered during QWW. These synergies could include direct "wants" to "haves" matching and indirect synergies which require innovative enabling technologies. The industrial experience and knowledge by IS practitioners is critical in identifying these opportunities, and it is a distinctive capability of ISL in creating and propagating IS activities. As this is a knowledge intensive process, IS practitioners use the proprietary tool (SYNERGie®) to record and retrieve past IS cases to aid in their recommendations. IS practitioners will subsequently progress the opportunities by facilitating meetings and liaise with environmental authorities to remove any barriers preventing the fruition of opportunities.

Analysis

IS creation process in theory and practice

A comparison of the IS creation steps in theory and in practice is show in Table 4. The most noticeable difference between the two is the absence of preliminary assessment step in practice. According to ISL, their IS creation process begins with recruiting members to build up a network of business members as having a critical mass is foundational to discovering synergistic opportunities.

While the remaining steps are largely analogous to one another, subtle differences in focus exist. In the step of business feasibility, ISL does not carry out business feasibility for businesses to avoid any liabilities as an IS facilitating company. Instead, ISL supports the business feasibility of IS opportunities by removing any barriers that may exist. For instance, ISL liaises with the local environmental authorities to either clarify environmental regulations or grant exemptions, without which may hinder the fruition of technically feasible IS opportunities.

In terms of opportunities identification, the literature provides an extensive range of tools supporting this step (e.g. databases, online waste exchanges, optimisation), providing an indication that this step may be probably driven by decision support tools.

However in practice, the process of opportunities identification is largely human-centric and expertise driven. Therefore, interactive networking sessions (i.e. QWW) are utilised to gather business representatives for joint brainstorming and opportunities mapping activities. During these sessions, IS practitioners play a critical role in assisting the identification of IS opportunities based on the data collected from the participating companies. An instance of a recent QWW, held in Metro Vancouver region, exchanged information regarding 130 resources and 166 potential synergistic matches (i.e. opportunities) were identified.

While the literature focuses on indicators to track the progress and achievements related to the implementation and monitoring step, in practice, the focus is on supporting the implementation of IS opportunities. For instance, active follow ups post QWW are done, such as preparing and sending reports to all participating companies to highlight potential synergistic matches to sustain the interest of companies, leading to the next stage of progress. Additionally, IS practitioners provide a facilitating function to gather potential companies and create meeting opportunities to enable IS opportunities to proceed.

In summary, while much similarity can be found between the literature discussions and in practice, upon closer examination, the emphasis within each step varies. Table 4 provides the comparison between the steps in theory and in practice.

Table 4: Comparison of steps in theory and practice

Steps in theory	**Steps in practice**
Preliminary assessment	Nil
Business engagement	Building the network
Opportunities identification	Quick wins workshop Opportunities mapping
Business feasibility	Facilitated synergy - Role of practitioners (barrier removal)
Implementation and monitoring	Facilitated synergy - Role of practitioners
Documentation and reinforcement	Outputs Report for implemented synergies

Tools used in practice

In the literature, discussions on decision support tools for IS are heterogeneous. Various categories of tools cover functions such as facilitating information flow and finding IS matches. Therefore, this may indicate the use of disparate tools in practice. However, this is not the case in practice. In the case of ISL, the key digital-based tool used in the field is SYNERGie®. This proprietary tool comprises multiple functions and supports across most of the steps of IS creation. For instance, it acts as a case study repository as IS practitioners are required to key in information regarding IS opportunities after the QWW and throughout the progress of individual IS opportunities. In this way, rich and detailed information regarding individual synergistic IS matches are documented. In turn, it supports the step of opportunities identification as IS practitioners are able to search and retrieve similar past IS matches, which provides additional stimulus for recommending potential IS synergies among participants.

Contrary to the literature discussions, mathematical optimisation and online waste exchanges are not used by ISL. While further interviews are planned to investigate the reasons, preliminary findings indicate that the lack of use of optimisation techniques is

due to the nature of synergies handled by ISL, while the use of online waste exchanges are not aligned to ISL's IS methodology which is mainly driven by IS practitioners and based on physical interaction among business participants.

In sum, digital tool presently used in practice provides basic functionalities (i.e. information storage, search and retrieval) to serve the needs of ISL's IS facilitation activities. Overall, the process of IS creation is primarily interactive and human-driven. Information is exchanged through formal and informal ways (e.g. networking events, QWW, forms and templates) and processed and analysed by humans (i.e. IS practitioners). Collectively, the effective combination of the use of physical interaction, digital support tool (i.e. SYNERGie®), expertise of IS practitioners and the commitment of ISL to engage businesses as well as to progress IS synergies opportunities forms ISL's unique capability as a firm. This unique capability has enabled ISL to achieve the large-scale orchestration of IS activities, and is arguably imperfectly imitable providing ISL its competitive advantage.

Table 5: Steps, tools and approaches used in practice

Step	**Tools / approaches**
Business engagement	Networking events IS practitioner Industry database
Opportunities identification	Quick Wins Workshop Site visit SYNERGie® (information search and retrieval function) IS practitioner (industrial knowledge)
Business feasibility	IS practitioner (barrier removal)
Implementation and monitoring	SYNERGie® (information entry)
Documentation and reinforcement	SYNERGie® (information entry)

Role of digitalisation

Given the knowledge driven process of IS creation, Grant et al. (2010) suggest that ICT plays an enabling role in knowledge transfer. This is evident in ISL's involvement in ongoing efforts of developing the next-generation SYNERGie® (SHAREBOX, 2017). Dubbed as "SYNERGie® 2.0", this enhanced tool will incorporate machine intelligence functions such as an ontology for smarter substance identification and data analytics algorithms designed to mine the vast amount of unstructured data built up previously by SYNERGie® and CRISP systems. When completed, SYNERGie® 2.0 is foreseen to transform the process of identifying IS opportunities from the current manual "pull" to an automatic "push" approach. While not designed as a replacement of IS practitioners, SYNERGie® is viewed to partially relief IS practitioners' day-to-day duties of searching for IS opportunities, freeing time to focus on activities such as engaging the industry, QWW and performing follow ups with companies.

Conclusion

This working paper investigates how digitalisation can enable IS practices. The paper focuses on ISL and its process of creating and organising IS, examining the various tools and approaches currently employed in practice. While human interaction was found to be

the primary means to orchestrate IS networks, the role of digital tools is anticipated to play a larger role in future based on current developments. These new tools will assist IS practitioners perform intelligent analysis of raw data collected from participants and provide recommendations to support IS practitioners in their job and increasing their productivity. It is also found that various efforts are ongoing to develop intelligent tools to support IS, replacing past tools that were mainly based on basic databases.

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